Geology BAER Report
Terwilliger Fire, Willamette National Forest
October 2018
Bart Wills

GEOLOGIC TYPE

The burned area landscape is split between of two distinct volcanic subgroups of the Cascade Range geologic province which was split by an extensional down-dropped graben seven millions years ago. The Cougar Fault trends north-south which cuts through the western edge of Cougar Reservoir. West of the Cougar Fault is the High Cascades, Pliocene to present in age, dominated by large stratovolcanoes, shield volcano, recent lava flows, cinder cones and tephra deposits. The High Cascades volcanics have been highly sculpted by Pleistocene glaciers, with abundant till and glacial landforms. East of the Cougar Fault, the “older” Western Cascades, Eocene to Miocene aged, is primarily composed of andesitic to basaltic volcanic lava flows, mudflows and tephra with steep, dissected mountain slopes. The eastern slopes are geologically mapped having deep seated landslide terrain. Earthflows and sumps at the toe of Boone Creek have been explored in recent. Subsurface hydrothermal circulation is expressed at the ground surface at Terwilliger Hot Springs.

The unstable geology of the area is susceptible to enhanced slope instability, erosion, and sediment delivery as a consequence of fire effects to soil and vegetation. Possible mechanisms of increased erosion and landsliding include: 1) increased surface erosion and delivery of sediment as well as increased channel scour due to increased post-fire peak flows from burned watersheds; 2) increased probability of shallow debris flow sliding along channels and inner gorges where toe slopes are susceptible to erosion from high flood flows; 3) channelized debris flows from burned areas with reduced root strength and increased sediment delivery to channels; and 4) reactivation of deep-seated landslides, possibly related to loss of evapotranspiration and associated elevated groundwater following tree mortality from fire. Landsliding and increased sediment delivery can present direct threats to stationary critical values from impact and destabilization, as well as indirect effects to critical values such as water quality for aquatic organisms, drinking water, and other defined beneficial uses.

CRITICAL VALUES

During the BAER assessment, a number of critical values from a variety of post-fire effects were identified. The values identified and the additional analysis performed to identify the level of threat, if any, and any proposed treatments.

The following table from the Forest Service Manual defines the critical BAER values for assessment:

Table 1. Critical Value Designations for BAER.

CRITICAL VALUES
HUMAN LIFE AND SAFETY
Human life and safety on or in close proximity to burned NFS lands.
PROPERTY
Buildings, water systems, utility systems, road and trail prisms, dams, wells or other significant investments on or in close proximity to the burned NFS lands.
NATURAL RESOURCES
Water used for municipal, domestic, hydropower, or agricultural supply or waters with special state or federal designations on or in close proximity to the burned NFS lands.
Soil productivity and hydrologic function on burned NFS lands.
Critical habitat or suitable occupied habitat for federally listed threatened or endangered terrestrial, aquatic animal or plant species on or in close proximity to the burned NFS lands.
Native or naturalized communities on NFS lands where invasive species or noxious weeds are absent or present in only minor amounts.
CULTURAL AND HERITAGE RESOURCES
Cultural resources on NFS lands which are listed on or potentially eligible for the National Register of Historic Places.

A number of locations and resources (see Table 2 below) were identified as potentially susceptible to impacts from geologic processes that might be accelerated post-fire. These are discussed in detail in the Burned Area Report (2500-8) and in the various resource specialist reports. A synopsis of some of the major critical values is represented below, and discussed with respect to the potential for geologic impacts in the following sections. Surface erosion, flooding, loss of control of water and sediment delivery are addressed separately in the soils and hydrology, and other resource reports.

Table 2: Geologic Critical Values

Critical Value	Location and Description	Nature of Geologic Threat
Human Life and Safety	FSR 1900	Rockfall
	FSR 1985-115	Pre-existing Landslide
Property	FSR 1900 at Boone Creek	Debris flow
	FSR 1900-500	Debris flow
	Terwilliger Hot Springs	Earthflow
	Cougar Dam and reservoir, Corps of Engineers*	Debris flow & sedimentation
Natural Resources	Water Quality	Debris flow & sedimentation
	Aquatic habitat	Debris flow & sedimentation

*Non-USFS values – Responsibility for emergency protection falls to the administrating agency

RESOURCE ASSESSMENT

The treat from accelerated geologic processes was evaluated using a number of qualitative and quantitative methods. Data sources include Geologic Map of the McKenzie Bridge Quadrangle, Lane County, Oregon (Priest, et. al., 1988), LiDAR and 10 meter DEM, active landslide inventories from Statewide Landslide Information Database for Oregon (SLIDO), soil burn severity classification developed by the BAER team. A distributed debris flow model developed and run by the USGS was used to help evaluate the risk of post-fire debris flows. The models, as well as other results of GIS analysis, is described below. Finally, field observations were used to validate the model results as well as define some risks that were not explicitly addressed by modeling. The geology map is displayed on Map 1.

The USGS debris flow model was run by Francis Kevin Rengers, Research Geologist, at USGS in Denver after he was provided with final soil burn severity layer derived from remotely sensed Burned Area Reflectance Classification (BARC) layer. The debris flow model is calibrated and best applied in the intermountain West. Results from the very different climate and vegetation of western Oregon may not represent debris flow probabilities as accurately as for the calibrated area. In particular, the following conditions differ markedly from the model design conditions:

The model design precipitation event is a 15-minute – 24mmh (short duration - high intensity storm) – these types of events are less typical for this region compared to the intermountain area. The longer duration storms of lower intensity generate most debris flows in western Oregon. The model calculates estimated likelihood and estimated volume of a debris flow looking at both channel and hillslope morphology and also calculates a Combine Hazard based on volume and likelihood estimates.

- The model does not address the loss of root strength or reduced evapotranspiration form tree mortality.
- The model does not address flash flooding (increased peak flows) or predict debris flow runout.
- The model does not address channel roughness, like large woody debris, which creates and may impede debris flows of moderate energy, is much more common in western Oregon channels than intermountain areas. Bearing in mind the factors that may affect model interpretations, the debris flow model is used in this assessment to describe the rick of debris flow generation. The model outputs include probabilities, volume estimates, and combined hazard rating for defined drainage basins and for individual channel segments. For this analysis, the basin probabilities for debris flow occurrence are used.

Initial observations in the field and from aerial reconnaissance indicated a number of drainages and hillslopes that appeared to have enhanced risk of slope failure and debris flow generation post-fire. Descriptions of the sites, field and model results, and conclusions regarding the level of risk are listed below. The USGS debris flow model results are displayed on Map 2.

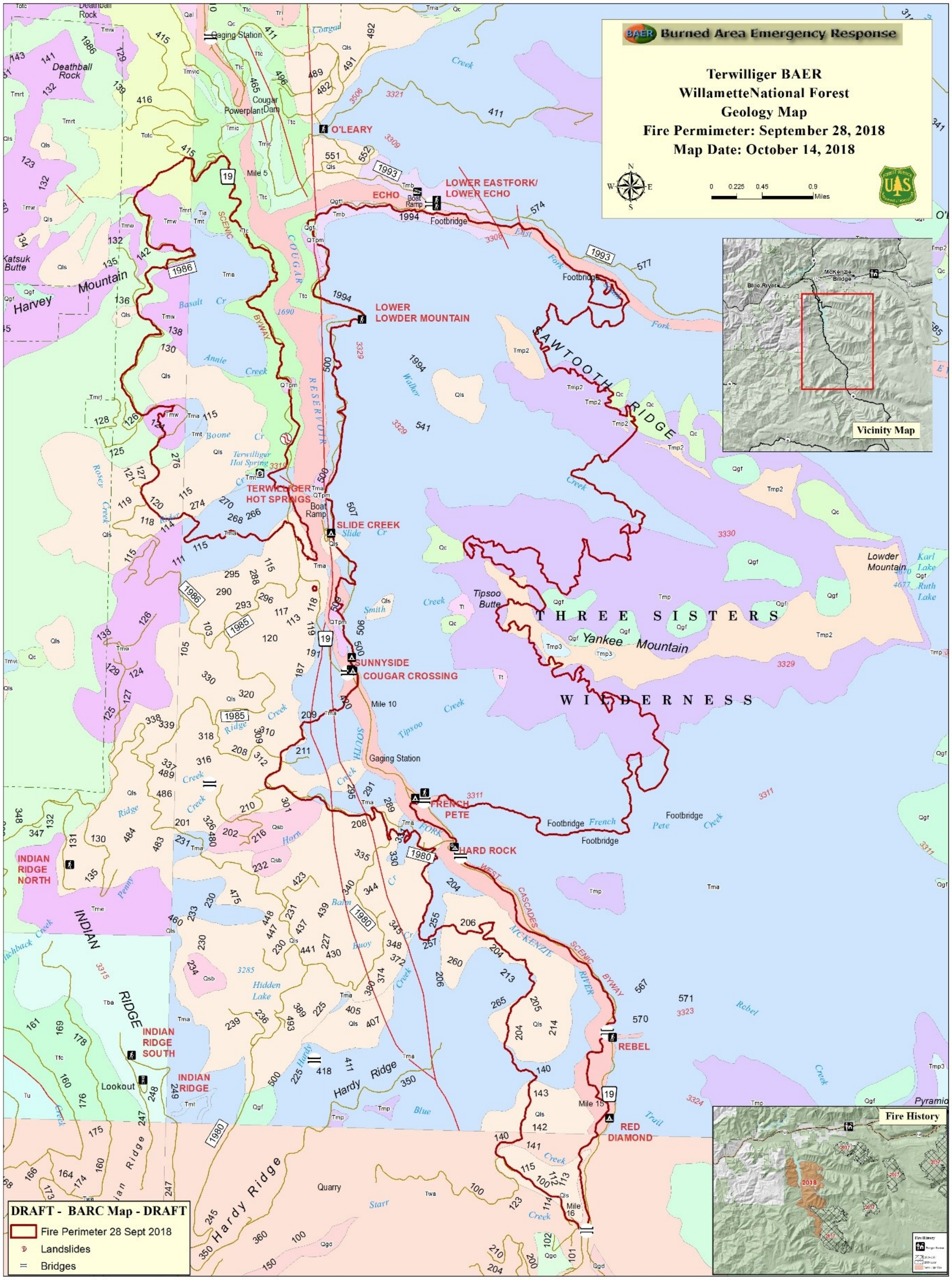

Figure 1: Geology Map

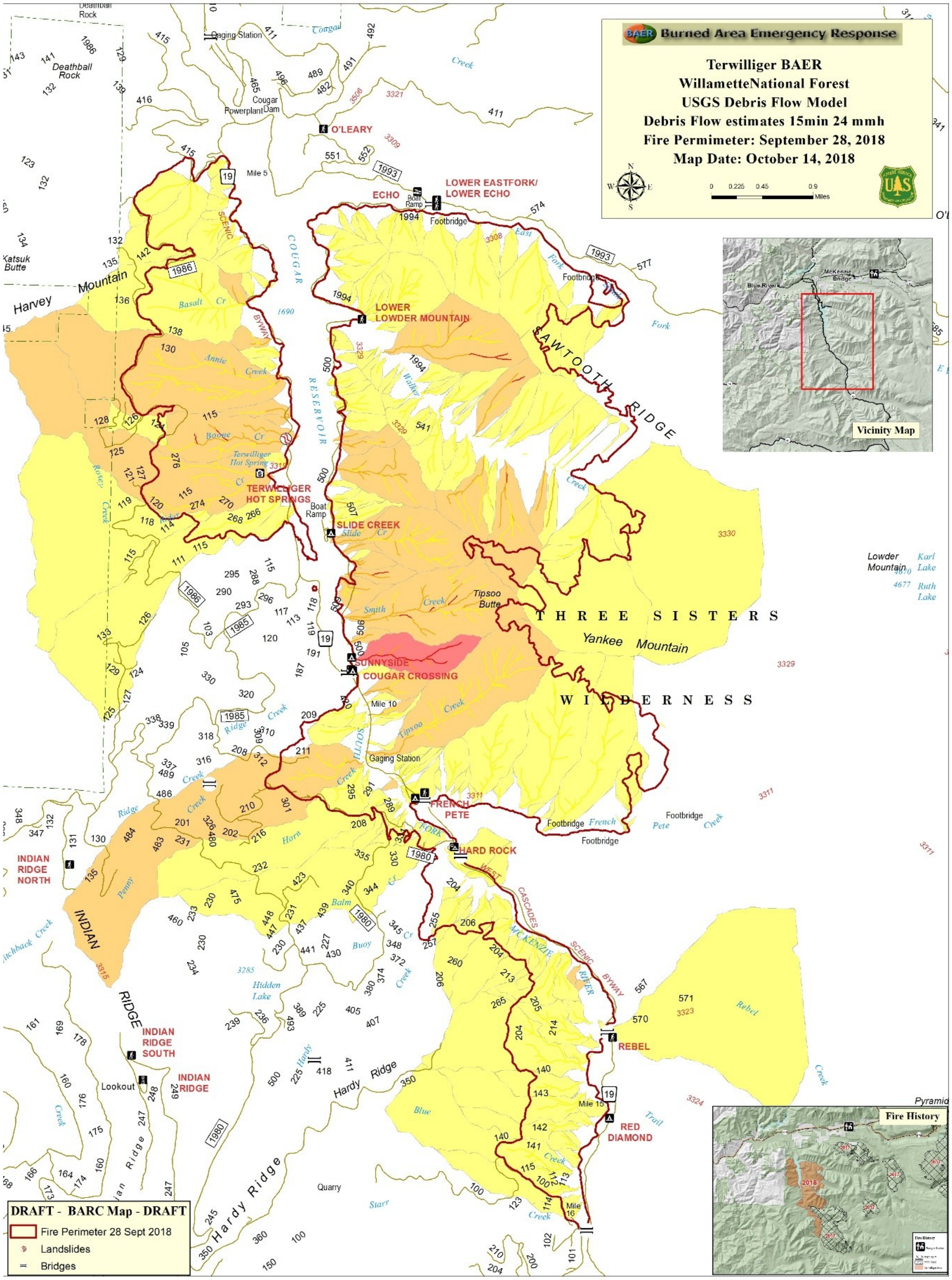
Burned Area Emergency Response
Terwilliger BAER
WillametteNational Forest
USGS Debris Flow Model
Debris Flow estimates 15min 24 mmh
Fire Permimeter: September 28, 2018
Map Date: October 14, 2018
0 0.225 0.45 0.9 Miles
Vicinity Map
Fire History
DRAFT - BARC Map - DRAFT
Fire Perimeter 28 Sept 2018
Landslides
Bridges
O'LEARY
ECHO
LOWER EASTFORK/
LOWER ECHO
LOWER
LOWDER MOUNTAIN
SAWTOOTH RIDGE
TERWILLIGER
HOT SPRINGS
SLIDE CREEK
SUNNYSIDE
COUGAR CROSSING
THREE SISTERS
WILDERNESS
FRENCH
PETE
HARD ROCK
INDIAN
RIDGE
NORTH
INDIAN
RIDGE
SOUTH
INDIAN
RIDGE
REBEL
RED
DIAMOND
Harvey Mountain
Yankee Mountain
Tipsoo Butte
Lowder Mountain
Cougar Dam
Powerplant
Gaging Station
Boat Ramp
Footbridge
Mile 5
Mile 10
Mile 15
Mile 16
Lookout
Quarry
Hardy Ridge
COUGAR RESERVOIR
SOUTH FORK
MCKENZIE RIVER
WEST CASCADES SCENIC BYWAY
Katsuk Butte
Deathball Rock
Hidden Lake
Karl Lake
Ruth Lake

Figure 2: USGS Debris Flow Model; Combined Hazard for Watersheds, 15-min/24mmh

Debris Flow Hazards

1. **FSR 1900 at Boone Creek –** Landslide inventory indicates deep seated landslide deposits mid-slope overlying Tuff of Cougar Reservoir (Ttc) which is a mix of highly weathered debris flow deposits, volcanoclastic material, and non-welded ash flow tuff. Historically, the weathered Ttc unit has moved as an earth flow and has been explored by USFS engineering geologists. Drilled piezometers and tilt meters were installed but were not found during field visits. The channels of Boone Creek are sinuous and rough with large logs and not representative of classic straighter debris with less roughness. The debris flow model the combined hazard of the main channel and hillslopes as moderate probability. Based on field evidence, this estimate may be accurate.

Table 3. Boone Creek Critical Value

Critical Value	Probability of Damage or Loss	Magnitude of Consequence	Risk	Treatment
Property	Likely	Moderate	High	Storm Inspection and Response (RT2)

Photo 1: Looking west across Cougar Reservoir at high severity burn in Boon Creek.

Photo 2: Lower Boone Creek, recent landslide scarp on north side of channel, approximately 400 feet from FSR 1900

2. **FSR 1985-115 at Boone Creek –** FSR 115 leads into the interior of a high burn severity portion of the fire and the upper portions of the inventoried deep seated landslide. Observations along FSR 115 revealed a small pre-fire landslide scarp approximately 60 feet wide and removed about two-thirds of the road prism from a small tributary along FSR 115 just north of Boone Creek main channel. The debris flow model Combined Hazard for the upper portion of channel is moderate to high and the Combined Hazard for the upper portion of hillslope is moderate. The tributary crossing the road landslide scarp has a Combined Hazard of high. Based on field evidence, sinuosity of the channel and high channel roughness, this estimate may be high.

Table 4. FSR 1985-115 Critical Value

Critical Value	Probability of Damage or Loss	Magnitude of Consequence	Risk	Treatment

Life	Possible	Major	High	Post-fire hazards present - recommend administrative closure (with existing gate)

Photo 3: FSR 1985-115 pre-existing prism failure; looking south, boundary between moderate and high severity burn area

3. **FSR 1900-500 at Slide Creek –** East side of Cougar Reservoir is very different from the deep seated landslide terrain on the west side. There are no inventoried landslide deposits east of the reservoir. The slopes are generally steeper and the channels run straighter, more like classic debris flow channels, that continue past Slide Creek Campground and into the reservoir (before it was filled). The field observations of Tipso Butte above Slide Creek is composed of steep, basaltic cliffs and talas chutes with no vegetation. Field observations into the lower slopes revealed a channel morphology that is deep, braided, and composed of numerous relic debris flow deposits. Channel roughness has extremely large, rounded boulders and old growth forest and large wood debris. The upper slopes were low to moderate burn severity and the lower slopes were mostly moderate to some high burn severity. Though moderate to high burn severity the slopes are stilled stacked with slightly burned down wood in lower slopes and channel adding to channel roughness. The debris flow model Combined Hazard for the channel is low to moderate and the Combined Hazard for hillslope is moderate. **Conclusion:** Based on field evidence, sinuosity of the channel, and high channel roughness; the debris model estimate may be high. To activate this debris material in this channel would take much more than the

designed stormed to activate. If debris would start, it likely would not reach campground or reservoir.

Photo 4: Slide Creek channel, moderate burn severity

Table 5. Slide Creek Critical Value

Critical Value	Probability of Damage or Loss	Magnitude of Consequence	Risk	Treatment
Property	Likely	Moderate	High	Storm Inspection and Response (RT2)

4. **FSR 1900-500 at Smith Creek –** Very similar channel as Slide Creek and shares the same steep cliffs and talas chutes. The channel is a slightly more sinuous than Slide Creek and does not have the massive relic debris flow channels of Smith are not present. However, Smith Creek has a more defined alluvial fan which Sunnyside Campground is located. The debris flow model Combined Hazard for the main channel is moderate with low potential tributaries. The Combined Hazard for hillslope is moderate. **Conclusion:** Based on field evidence, sinuosity of the channel, and high channel

roughness; the debris model estimate may be high. To activate this debris material in this channel would take much more than the designed stormed to activate. If debris would start, it likely would not reach campground or reservoir.

Photo 5: Lower Smith Creek, moderate burn severity, note roughness of channel

Table 6. Smith Creek Critical Value

Critical Value	Probability of Damage or Loss	Magnitude of Consequence	Risk	Treatment
Property	Likely	Moderate	High	Storm Inspection and Response (RT2)

FSR 1900-500 at unnamed creek – This unnamed creek lies approximately halfway between Sunnyside and Cougar Crossing Campgrounds. It has a relatively small drainage area as compared to Slide and Smith Creeks above. This drainage also begins at the steep cliffs of Tipso Butte and has a moderately sinuous channel with small alluvial fan development. The burn severity of the upper slopes was unburned to low, the middle to upper slopes high burn severity and middle to toe slopes low burn severity. Within the high burn severity were steep cliffs low on the ridge. The debris flow model Combined Hazard for the main channel is high and the Combined Hazard for hillslope is high. Of all the potential debris flow basin within the fire's perimeter, this unnamed creek has the high probability according to the debris flow model. **Conclusion:** Based on aerial reconnaissance and sinuosity of the channel, the debris model estimate may be high. Similar to Slide and Smith Creeks, to activate the debris material in this channel would take much more than the designed storm. If debris would start, it likely would not reach the reservoir.

Table 7. Unnamed Creek between Sunnyside and Cougar Crossing Campgrounds Critical Value

Critical Value	Probability of Damage or Loss	Magnitude of Consequence	Risk	Treatment
Property	Likely	Moderate	High	Storm Inspection and Response (RT2)

Photo 6: Aerial, looking north at high burn severity on the unnamed creek (located at FSR 1900-500 between Sunnyside and Cougar Crossing Campgrounds)

Rockfall Hazards

1. **FSR 1900 (Aufderheide Drive National Forest Scenic Byway) –** FSR 1900 is National Forest Scenic Byway, economically important to the areas of McKenzie and Blue River, and major connector road from McKenzie to Oakridge. The road also provides access to the very popular Terwilliger Hot Springs Recreation Site. Rockfall is the natural downward motion of a detached block or series of blocks with a small volume involving free falling, bouncing, rolling, and sliding. FSR 1900 was constructed by cutting and over-steepening rock outcrops to access around the west of the Cougar Reservoir. Over time the fractures in the rocks expand by freeze-thaw processes which slowly loosens the rock face and gravity pulls the rock down. Minor rockfall along the FSR 1900 is common with a rare slope failure and rock slide which closes the road for long periods of time. In December 2017, a rockslide closed the road for six months. Fire burn severity along the road is generally **LOW** but fire effect will allow more moisture into the rock fractures possibly increasing potential for rockfall. Fire Suppression funded a scaling service

contract to mitigate the rockfall hazards along the road but did not eliminate the hazard. **Conclusion:** Rockfall hazards have increased along FSR 1900 and FSR 1900-500 from the fire.

Photo 7: Recent rockslide on FSR 1900; this rockslide closed the road for 6 months:
Dec 2017 – July 2018

2. **FSR 1900-500 –** Similar to FSR 1900, due to over-steepened rock slopes and low burn severity has increased the rockfall hazard along FSR 1900-500.

Table 8. FSR 1900 and FSR 1900-500 Rockfall Critical Value

Critical Value	Probability of Damage or Loss	Magnitude of Consequence	Risk	Treatment
Life	Possible	Major	High	Road Hazard Signs (P1a)

Terwilliger Hot Spring Recreational Site - are very popular geothermal pools that are run by USFS concessionaire contract. The site is very important economically to the community and to the McKenzie River Ranger District recreation program. The water source is above the topmost pool where the spring flows from a rock face at approximately 111 degrees Fahrenheit and cascade down to three lower pools. The upper pools is carved out of the hillside and the pool floors are mostly on bedrock. Over the years people have built up four pools out of river stones and the pools were lastly renovated in 2009. The hillslope above the upper pool has been highly modified and over-steepened with one documented rockfall that almost hit a woman and child. The hot springs flow out of the contact between the inventoried deep seated landslide deposits and the lower Ttc geologic unit (mix of highly weathered debris flow deposits, volcanoclastic material, and non-welded ash flow tuff). The over-steepening of the slope has partially removed the toe of the landslide materials. Burn severity on the slopes above the pools was mapped at Moderate and has removed most of the roughness from the slope. Field observations of the slope revealed over one dozen large cobble sized to small boulder sized rocks exposed with potential to mobilize and fall into the upper pool. No evidence of recent movements and no observed tension cracks on slopes above pools. However, reactivation of deep-seated landslides, possibly related to loss of evapotranspiration and associated elevated groundwater following tree mortality from fire. Possible Loss of soil strength over next 5-10 years from loss of root strength. The debris flow model Combined Hazard for the upper portion of channel is low and the Combined Hazard for the upper portion of hillslope is moderate. Based on field evidence, moderate steep slopes with moderate channel sinuosity and moderate channel roughness, this estimate may be accurate. Based on field observations, a small or moderate debris flow in the channel of unnamed tributary (locally known as “coldwater creek”) running parallel to the pools could overflow the channel and undermine the boulders and mortar holding the pools together which would cause all the pools to unravel below.

Photo 8: Looking north along west side of reservoir, center high severity burn is Boone Creek, right side is moderate burn severity in area of Terwilliger Hot Springs.

Table 9. Terwilliger Hot Spring Rockfall Critical Value

Critical Value	Probability of Damage or Loss	Magnitude of Consequence	Risk	Treatment
Life	Possible	Major	High	Site Closure (P10)
Property	Possible	Major	High	Infrastructure Protection (P6)

Cougar Dam – The dam impounds the South Fork McKenzie River creating Cougar Reservoir which has a storage capacity of 219,000 acre feet. The Dam and Reservoir is managed by the U.S. Army Corps of Engineers for the purpose of providing flood risk management, hydropower, water quality improvement, irrigation, fish and wildlife habitat, recreation, storage, and navigation. Cougar Dam is 519-foot tall rockfill dam with concrete spillway and generates 25 megawatts of hydroelectric electric power. In 2005, constructed a temperature control facility

which help regulate the water temperature released to the river below Cougar Dam in an attempt to reduce the negative effects on salmon migration. The fire completely surround the dam and reservoir. The Corps of Engineers are concerned about the potential of landslides, debris flows, increased sedimentation, woody debris, and degraded water quality. **Conclusion:** There is overall low potential of a major debris flow or earthflow entering the reservoir. The likelihood of some increased sedimentation this winter is inevitable, however, water quality and increased sedimentation into reservoir will be very minor at worst. Cougar Dam is a non-USFS facility it does not fall under BAER assessment and protection of the facility is the responsibility of the managing agency.

Table 10. Cougar Dam Critical Value

Critical Value	Probability of Damage or Loss	Magnitude of Consequence	Risk	Treatment
N/A	N/A	N/A	N/A	N/A

Photo 9: Looking down slope immediately above Terwilliger Hot Springs, moderate burn severity, steam in center left background from hot springs

GEOLOGIC RESPONCE

Modelling results generally support field observations that indicate there will be limited post-fire geologic response from a 10-year recurrence interval storm event. Only 7% of drainages have a probability greater than 0.40 for the occurrence of debris flows. Drainages at highest risk for debris flow initiation include Boone Creek, unnamed drainage north of Slide Creek, unnamed drainage between Slide and Smith Creeks, and Smith Creek (see Figure 3 below).

The model design precipitation event is a 15-minute – 24mmh (short duration - high intensity storm) – these types of events are less typical for this western Oregon compared to the intermountain area. The western Cascades receive longer duration storms of lower intensity which generate most debris flows. The model calculates estimated likelihood and estimated volume of a debris flow looking at both channel and hillslope morphology and combines these to calculate a Combine Hazard. Weakness in the debris flow model for the Terwilliger Fire are:

- The model does not address the loss of root strength or reduced evapotranspiration form tree mortality.
- The model does not address channel roughness, like large woody debris, which creates and may impede debris flows of moderate energy, is much more common in western Oregon channels than intermountain areas. Bearing in mind the factors that may affect model interpretations, the debris flow model is used in this assessment to describe the rick of debris flow generation. The model outputs include probabilities, volume estimates, and combined hazard rating for defined drainage basins and for individual channel segments. For this analysis, the basin probabilities for debris flow occurrence are used.

Initial observations in the field and from aerial reconnaissance indicated the drainages highlighted have a lower likelihood of debris flow discharge than the model predict due to sinuosity of stream channels and and roughness of channels.

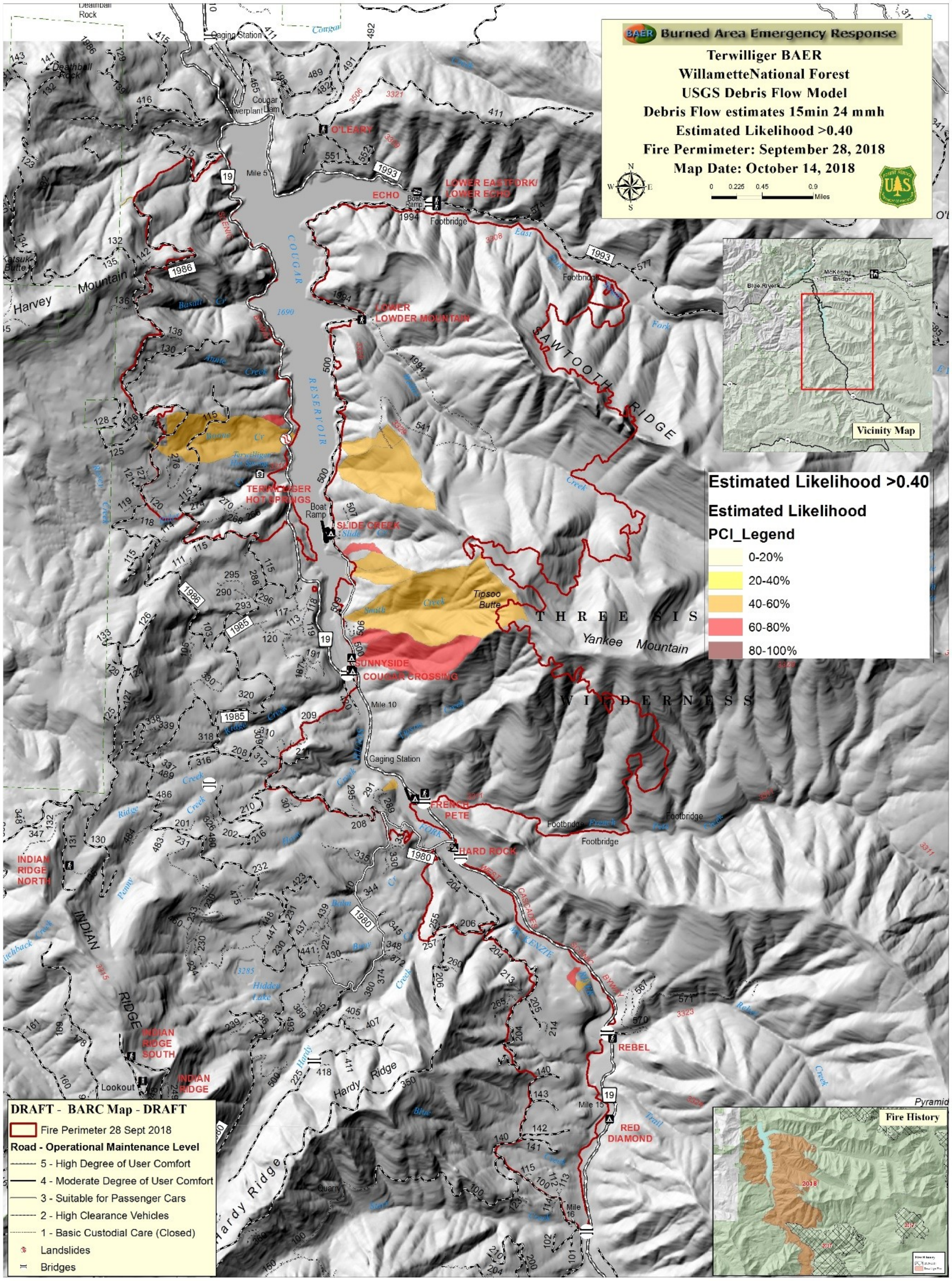

Figure 3: USGS Estimated Likelihood of debris flow based on 15-min/24mmh (short duration/high intensity storm). Only 7% of drainages have a probability greater than 0.40 for the occurrence of debris flows.